

ICFD modeling of final settlers - developing consistent and effective simulation model structures - DTU Orbit (08/11/2017)

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Summary of key findings The concept of interpreted computational fluid dynamic (iCFD) modelling and the development methodology are presented (Fig. 1). The 1-D advection-dispersion model along with the statistically generated, meta-model for pseudo-dispersion constitutes the newly developed iCFD concept. The case of secondary settling tanks (SSTs) is used to demonstrate the methodological steps using the validated CFD model with the hindered-transientcompression settling velocity model by (10). Factor screening and latin hypercube sampling (LSH) are used to degenerate a 2-D axisymmetrical CFD model structure (10) into a one-dimensional (1-D) advection-dispersion model structure. The boundary condition sets, obtained in the LHS, are imposed on the 2-D CFD simulation model of the SST. In the framework, to degenerate the 2-D model structure, CFD model outputs are approximated by the 1-D model through the calibration of three different model structures for D , the pseudo-dispersion coefficient. Correlation equations for the D parameter (meta-models) are then identified as a function of the selected design and flow boundary conditions, and their accuracy is evaluated against the D values estimated in each numerical experiment. The evaluation and validation of the iCFD model structure is carried out using scenario simulation results obtained with parameters sampled from the corners of the LHS experimental region. For the studied SST, additional iCFD model development was carried out in terms of (i) assessing different density current sub-models; (ii) implementation of a combined flocculation, hindered, transient and compression settling velocity function; and (iii) assessment of modelling the onset of transient and compression settling. Results suggest that the iCFD model developed for the SST through the proposed methodology is able to predict solid distribution with high accuracy -- taking a reasonable computational effort -- when compared to multi-dimensional numerical experiments, under a wide range of flow and design conditions. The iCFD models developed are intended to comply with the consistent modelling methodology (1). iCFD tools could play an important role in reliably predicting WWTP performance under normal and shock-loading (7). Background and relevance System analysis tools typically comprise numerous sub-models, identified so that the computational effort taken through system analysis exercises is kept to a minimum (4). Consequently, detailed information related to, for instance, design boundaries, may be ignored, and their effects may only be accounted for through calibration of model parameters used as catchalls, and by arbitrary amendments of structural uncertainty propagations to outputs (e.g. 1-D SST). The present study aims at using statistically designed CFD simulation scenarios with different design and flow boundary conditions to identify consistent and effective 1-D structures. The attempt of combining CFD simulations and statistical tools is inspired by the work of (6). Further details are shown in (5). Results and discussions Factor screening. Factor screening is carried out by imposing statistically designed moderate (under-loaded) and extreme (under-, critical and overloaded) operational boundary conditions on the 2-D CFD SST model (8). Results obtained in the statistical analysis of the CFD outputs in the extreme scenario suggest that the loading conditions characterised with feed solid concentration (X_{in}), SST overflow rate (Q_{ov}), recycle ratio (R), and, to a minor extent, the inlet height (H_{in}), are the four significant factors, impacting the SST performance, in terms of sludge blanket height (SBH), solids concentration in recycle of activated sludge (XRAS) and solids concentration in SST effluent (X_{eff}). Statistical results obtained in the moderate scenario indicate five factors significantly influencing the SST performance, i.e. X_{in} , Q_{ov} , R , sidewater depth (SWD) and H_{in} . It should be noted that the baffles installed in the SST inlet and outlet (characterised with 4 parameters), are found to have negligible effect compared to the aforementioned five factors. Internal baffling probably has a positive effect, especially on effluent quality albeit at a lower order of magnitude not visible in our results. LHS. Based on the screening study, the five significant factors used in the subsequent LHS are X_{in} , Q_{ov} , R , SWD and H_{in} . The LHS yielded 50 CFD simulations, and the outputs, in terms of SBH, XRAS, X_{eff} , total amount of solids in SST (M_{tot}) values, are extracted from the steady-state solution, and then used to perform the iCFD model identification. iCFD model identification. We assess the 1-D model structure in terms of setting the feed location (layer) and transient/compression threshold concentration, XTC. Using the CFD outputs from LHS, we assessed nine different model structures based on literature (1; 3; 2; 10; 9) and on more recent considerations (Fig. 2a). Validation tests were done using the CFD outputs from extreme scenarios. The most effective model structure (relatively low the sum of square of relative errors, SSRE, and computational time) obtained is that in which the XTC is set at the concentration of the layer just below the feed-layer. The feed-layer location is set to the highest location where $X > X_{in}$ (solids concentration in SST influent). An effective discretization level (computational time/numerical error) is assessed by approximating the LHS outputs with an iCFD model discretised using 10-200 layers. Solutions obtained show convergence, and the discretisation scheme with 60 layers seems an effective trade-off. Identification and validation of the D -model. To identify a formulation for the pseudo-dispersion coefficient in the iCFD model, we tested three structural scenarios by defining (i) one single pseudo-dispersion coefficient (D_0) for all the layers; (ii) one pseudo-dispersion coefficient (D_1) above and another pseudodispersion coefficient (D_2) below the feed-layer; (iii) one pseudo-dispersion coefficient (D_f) just around the feed-layer. These scenarios were inspired by literature (1; 2; 9). As for the D_0 -iCFD model, values of SSRE obtained are below 1 with an average SSRE=0.206. The simulation model thus can predict the solids distribution inside the tank with a satisfactory accuracy. Averaged relative errors of 8.1 %, 3.1 %, 16.1 % and 11.8 % are observed for SBH, XRAS, X_{eff} and M_{tot} , respectively. A statistical analysis of the calibrated D_0 compared to the five input factors is performed. In addition to the elementary factors, four interactions are found significant: X_{in}^2 , $X_{in} \cdot H_{in}$, $R \cdot H_{in}$ and $X_{in} \cdot Q_{ov}$. A correlation is obtained between the loading and design factors and D_0 with an R^2 of 0.853 (adjusted $R^2=0.819$), i.e. Eq. 1. D_0 values predicted with Eq. 1 are compared to the values estimated using 1-D model approximation of the 50 CFD outputs, and results suggest a relatively effective correlation as well (Fig. 2b). The three iCFD models, employing different formulations for D , calibrated using the meta-models (Eq. 1 for D_0), are used to approximate the CFD outputs obtained in the extreme scenarios. Using the D_0 -iCFD model, the solid distribution at the corners of the LHS experimental region can be predicted with the highest accuracy (average SSRE=0.71), thereby validating the simulation model. For $D_{1,2}$ -iCFD, the meta-model is limited in calculating D , and the model fails the validation test using the extreme scenario (SSRE=386). Using the D_f -iCFD model, the predictive accuracy obtained is comparable with that obtained with the D_0 -iCFD (compare 1.73 to 0.71).

The computational time required through simulation with Df-iCFD, however, is significantly higher than that obtained with the D0-iCFD (on average 3.5 times longer). Therefore, this study concludes that, considering the capability and usability - in terms of complexity and computational time - the D0-iCFD model is preferred.

General information

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